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Office of Communication,
Navigation, and Surveillance
Washington, DC 20591

Heliport Lighting – Technology Research

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Under Contract to:

Science Applications International Corporation
Air Transportation Systems Operation
Arlington, Virginia 22202

November 1998

Final Report

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U.S. Department of Transportation

Federal Aviation Administration

NOTICE

U.S. Department
of Transportation
**Federal Aviation
Administration**

800 Independence Ave., S.W.
Washington, D.C. 20591

NOV 20 1998

Dear Colleague:

Enclosed are three Federal Aviation Administration (FAA) technical reports that you may find of interest:

FAA/ND-98-1, Heliport Lighting - Technology Research

FAA/ND-98-2, Heliport Lighting - Configuration Research

FAA/ND-98-4, Heliport Lighting – U. S. Park Police Demonstration

Also of interest is a previously distributed FAA report: Evaluation of a Heliport Lighting Design During Operation Heli-STAR, FAA/ND-97/20. These reports document the initial phase of an FAA/Industry effort to develop a cost-effective heliport lighting system for Global Positioning System (GPS) helicopter approaches. They speak of new technologies that could be of use as part of a heliport lighting system as well as military lighting systems that could be useful if optimized for civil heliport applications. The reports also document previous research that has attempted to determine what helicopter pilots need in the way of visual cues for heliport approaches at night or in poor weather.

While these reports address a wide range of heliport lighting issues, they raise more questions than they answer. The possibilities of dealing with these issues are exciting but the range of potential solutions is very broad. We do not yet have answers to all the questions of interest to those who wish to implement improved heliport lighting systems. Additional work is needed. In particular, candidate lighting systems need to be developed, installed, and tested in a variety of operational scenarios in different environments throughout the country. If we were to do all that seems appropriate, the cost would far exceed the available funding. Thus, we are looking for ways to achieve the maximum near term benefits within the limits of available funding. With this in mind, we look to Industry for their recommendations.

The FAA is looking for ways to accomplish more with smaller budgets. By working in Government/Industry partnerships, we have seen that it is possible to do more with less. After reviewing the reports listed above, we request that you write us with your advice on what future

heliport lighting research efforts would be most likely to meet your operational requirements. Please send your comments to:

Federal Aviation Administration
General Aviation and Vertical Flight Program Office, AND-710
Attn: Robert D. Smith
800 Independence Ave. SW
Washington DC 20591

By soliciting Industry's advice, we hope that your ideas will better enable us to choose those heliport lighting research projects that will meet your needs. Your advice would be most effective if we could receive it by January 15, 1999. We appreciate your assistance and we look forward to continued FAA/Industry cooperation on matters such as this.

Steve Fisher Steve Fisher
Acting Manager, General Aviation and
Vertical Flight Program Office

U.S. Department
of Transportation
**Federal Aviation
Administration**

800 Independence Ave., S.W.
Washington, D.C. 20591

NOV 20 1998

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16. Abstract

This document reports on the initial phase of a program to develop a cost-effective heliport lighting system for Global Positioning System (GPS) helicopter approaches. The investigation into lighting technologies shows that many of the currently available technologies would be effective. These include: electroluminescent panels, light pipes or bars, strobes, cold cathode strobes, identification beacons and point light sources.

Results showed that future experiments with helicopter GPS approach lighting arrays should refine the geometric pattern of the light sources, the spacing of the light sources, the direction of the light line, the intensity of the light source, the color of the light source, the pulse duration for any strobing lights, and the potential use of special types of lights and filters. Additionally, the light sources should contrast with background lights. Line-up and glideslope lights should provide a sufficient visual angle disparity to cue off-course conditions and the required correction.

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Finally, for very special field support in the experiment involving the Mirror Optical Landing Systems (including flying a number of test approaches and preparing resulting rating data), thanks are offered to Mr. Dan Norman and the pilots and flight crews of the Erlanger Medical Center "Life Force" operation of Chattanooga, Tennessee.

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1. INTRODUCTION

This report documents an initial part of a comprehensive program to develop a cost-effective lighting system to support GPS instrument approaches to heliports. This report specifically identifies lighting technologies suitable for use now and those for potential future systems.

The helicopter has been considered a specialized air vehicle based on its ability to hover. However, the development of airways, approaches, and other infrastructure to meet the needs of helicopters has lagged behind that of fixed-wing aircraft. The advent of highly reliable turbine-powered helicopters has resulted in a new look at the helicopter as a vehicle able to meet some of the short-haul transportation needs. With the urbanization of the United States and the associated congestion, vertical flight aircraft have much to offer the nation in terms of transportation benefits. However, the lack of an infrastructure continues to inhibit the realization of widespread helicopter use as a part of the solution to transportation needs.

The advent of the Global Positioning System (GPS) with its ability to allow accurate navigation at any altitude without reliance on ground-based equipment has been a breakthrough for helicopter infrastructure. This has already led to the establishment of a number of helicopter-specific, non-precision approaches around the country. The ability to operate "all-weather" is of interest to segments of the helicopter industry, especially to air ambulance operators. In this case, the ability to operate in poor weather conditions can be a matter of life or death. For instance, during the first six months of use of the first established GPS non-precision approach at Erlanger Medical Center in Chattanooga TN, fourteen lives were saved that otherwise would have been lost.

Although non-precision GPS approaches have greatly improved the National Airspace System (NAS) for helicopters, true all-weather capability at heliports is still lacking. The major remaining difficulty involves the air infrastructure, since for some time some helicopters with modern flight director/autopilot systems have had the capability to make automatic and hand-flown precision instrument approaches to 50-foot hovers. The Federal Aviation Administration (FAA) has recognized this lack of helicopter-specific instrument approach capability and has funded research into the problems of Terminal Instrument Procedures (TERPS) and instrument approaches for helicopters (reference 1). The results of research reported herein follow requirements established by that previous work and other related work efforts.

2. PROBLEM STATEMENT

The Helicopter Instrument Approach Lighting Array faces a number of constraints. Primary among these constraints is the location of the heliport. Other limits may include the types of operation and operational aspects such as co-location with an airport. Table 1 provides a tabulation and depiction of the constraints on heliport lighting systems. From this table we can see that the different possibilities create a problem in determining one lighting array that is good for all cases. Remote sites and airport locations may have ample real estate upon which to locate the array, while city center and rooftop locations will generally have very limited space. In addition, remote sites may have problems obtaining adequate power to operate the system. However, a major limiting factor will be the cost of the system, since municipalities, private companies, or individuals will pay for lighting at all of these locations. Therefore, any lighting array for GPS instrument approaches must be cost effective.

In addition to the constraints of location, the approach lighting array must provide for the following items:

1. Acquisition of the heliport after breaking out of the weather. Although designed for a precision approach, the array should also permit acquisition of the heliport after breaking out from a non-precision approach as well as during visual conditions.
2. Safe lineup and vertical guidance to the hover point over the helipad.
3. Spatial orientation during the visual segment to included
   a. Depth perception for the pilot.
   b. Vertical orientation to prevent pilot vertigo.
4. Closure rate on the helipad.
5. Visual cues for final flare and touchdown.

The Federal Aviation Administration has developed two helicopter precision lighting arrays known as HALS (reference 2) and HILS (reference 3). The HALS requires a large amount of real estate. Helicopter pilots using these systems complain that most of the array is below or behind them when they break out of the weather in low-ceiling conditions. Pilot comments obtained in reference 1 indicate that much of the lighting array should be beyond the helipad rather than on the approach side.

In conducting this study, the UTSI project team considered several other factors in addition to those already mentioned. Among those factors were:

1. Background lighting that might come from a city center location.
2. Initial and life cycle costs for the proposed arrays.
3. Availability of utilities, both electrical power and cooling water, if necessary, for systems such as lasers.
4. Array standardization for a variety of locations.

Table 1 Heliport Operations Synopsis

Heliport Location	Types Of Operations	Unique Operational Aspects
City Center-Ground Level	IFR and VFR Operations: Business, Air Ambulance, Construction, Military, Tourist, Air Taxi	Ambient Light Problems, Noise, Number of Operations may be high, Obstruction Avoidance
City Center-Roof Top Level	IFR and VFR Operations: Business, Air Ambulance, Construction, Military, Tourist, Air Taxi	Ambient Light Problems, Noise, Number of Operations may be high, Limited Area for Lights
Medium Size City-Ground Level	IFR and VFR Operations: Business, Air Ambulance, Military	Low site investment, noise larger concern
Small City-Ground Level-Dual Use	IFR Point in Space or VFR Operations: Business, Air Ambulance, Special Purpose, Agricultural	Low site investment, noise larger concern, sites may be dual-use, parking lot or football field.
Remote Operations-Established Site	VFR or IFR Point in Space: Construction, Recreational, Forestry, Air Ambulance	No ambient light, noise concerns, and operations of limited nature
Oil Platforms	VFR, IFR to Central Location (modified Point in Space): Air Ambulance, Construction	Limited area for lights, difficult atmospheric conditions in ocean environment
Instrument Approach to Displaced Landing Pad	VFR or IFR to Heliport with VFR Lead-In	Lighting array displaced for final touchdown location

Note: Instrument Flight Rules (IFR)
Visual Flight Rules (VFR)

It is important to note that the characteristics of the light source (within its heliport environment) and the corresponding human visual response (within the cockpit environment) must be treated with equal importance in designing and testing lighting arrays.

3. LIGHTING TECHNOLOGIES

3.1 BACKGROUND

This research has considered a number of lighting technologies for potential application to GPS instrument approaches in instrument meteorological conditions (IMC). As a first step in developing information on the various available technologies, a detailed search of the literature database was conducted. The results of this activity are contained in Appendix A, Bibliography of Technical References.

By considering (and taking advantage of) the physiology of the human vision system, effective designs that provide an improvement over the present state-of-the-art can be produced. Perceptions of brightness, movement, color, contrast, and depth should all be involved to the greatest "scientific" extent possible in developing a suitable lighting system. The geometry of both the heliport and the aircraft will also play an important part in the criteria.

The objective of the lighting technologies investigation was to define the possibilities for various systems in terms of potential results, and at the same time carefully avoid systems which would produce negative effects.

Illusions created by lighting systems can, in the aviation field, produce catastrophic consequences. A bright light, for example, is generally assumed by the observer to be closer than a dim light (in absence of other visual information). If the light source intensities are not thus matched to the geometry, the visual information received by the pilot can be entirely the opposite of the actual situation. The objective then should be to combine light sources with a system that reinforces the real situation, provides adequate cues, and reduces chances of illusionary errors.

Pilot workload reduction represents another worthy objective in lighting system design. Once the transition to visual conditions if made (at breakout), the lighting system should permit the pilot to complete all phases of the landing maneuver without any requirement to return his gaze to the cockpit interior for instrument guidance.

3.2 OPERATIONAL REQUIREMENTS

The several phases of a landing maneuver require varying cues in response to the need for visual information. Table 2 summarizes the requirements to be considered.

Cost of equipment, installation, operation, and maintenance of a lighting system are all major economic considerations. The technical sophistication of any system, the number of fixture units required, and the component replacement frequency will all need to be carefully weighed when constructing a recommendation.

Table 2 Heliport Visual Landing Aids Operational Considerations

Operational Segment	Operation	Pilot Action	Requirement
Acquisition at Breakout	Location (where is pad) Orientation (which way is up)	Identify pad Relate to horizon	Provide pilot with positive identification. Select pad from background light (consider off-course condition)
Approach	Line up Glideslope	Adjust direction Adjust altitude	Line up cue Glideslope cue
Closure	Control rate of closure	Decelerate	Closure rate cue
Landing	Flare Hover Touchdown	Maintain visual contact Center helicopter Settle to pad	Provide 3-dimensional information of helicopter position related to the pad

General Operational Criteria Notes:

1. All lighting displays should be of minimum complexity in order to avoid increase in pilot workload.
2. All lighting should be usable night or day.
3. Light fixtures should be located to avoid creating obstructions.
4. Light fixtures should be located close to the heliport for power, control, and real estate considerations.
5. All lighting should be usable in IMC. Special attention should be given to spatial orientation.
6. Major experimentation with the following variables should be considered:

   Geometric pattern of light source
   Spacing of light sources
   Light line direction
   Light source intensity
   Light source color
   Light source pulse and duration
   Use of special types of lights and filters

3.3 GEOMETRIC REQUIREMENTS

Certain geometric elements are important to the proper layout and installation of lighting systems. In the case of heliports the following are critical:

- Light source arrangement (form)
- Light source spacing (dimension)
  - ◊ Horizontal (length and width)
  - ◊ Vertical (Height)

In addition to the heliport considerations mentioned above, it is also essential to consider the geometric visual capabilities of the observer. In that regard, each of the approach guidance systems (line-up and glideslope) must provide visual angular disparity between the system elements that are sufficient to be discerned from the appropriate range. The angular disparity must not be so great as to fail to provide the required cue. Experimental works conducted by Whittenberg, Vaughn, et al (reference 4) produced some well-researched criteria which is available as guidance in heliport lighting design:

> <u>Line-up</u> – In order to provide lateral displacement guidance, the length of a line of light collinear with the approach path should subtend a minimum visual angle of 19 minutes (0.32 degrees).
>
> <u>Line-up</u> (alternate) – In order to provide lateral displacement guidance, the separation between point light sources should range from 9 minutes (0.15 degrees) to 20 minutes (0.33 degrees) of visual angle. (Assume for experimental purposes, that line source criteria will be approximately the same as the point source criteria described herein.)
>
> <u>Glideslope</u> – In order to provide vertical displacement guidance, the separation between light sources should range from 9 minutes (0.15 degrees) to 49 minutes (0.82 degrees) of visual angle. (Assume for experimental purposes, that line source criteria will be approximately the same as the point source criteria described herein.)
>
> <u>Orientation</u> – In order to provide a horizontal reference, the length of a horizontal light line should subtend a minimum visual angle of 132 minutes (2.20 degrees).
>
> <u>Orientation</u> (alternate) – In order to provide a horizontal reference, the separation between light sources should range from a minimum of 220 minutes (3.67 degrees) to a maximum of 440 minutes (7.33 degrees) of visual angle.

Figure 1 illustrates the correct visual angles determined by the research.

Finally, the geometry of the helicopter cockpit itself will influence the location of all proposed lighting arrays. Part 27 (Airworthiness Standards for Normal Category Rotorcraft) and Part 29 (Airworthiness Standards for Transport Rotorcraft) of the FAA Regulations are not specific in terms of cockpit geometrical design, stating simply that, "each pilot's view (must be) sufficiently extensive, clear, and undistorted for safe operation." The design geometry is thus left to the manufacturer. Significant variations have occurred as a result.

3.4 LIGHTING SYSTEMS TECHNOLOGIES

<u>Electroluminescent Lighting</u>

Electroluminescent lighting uses phosphors to generate light as opposed to heat. The construction of the lamp is similar to that of a capacitor. It consists of two conducting surfaces with a dielectric between them.

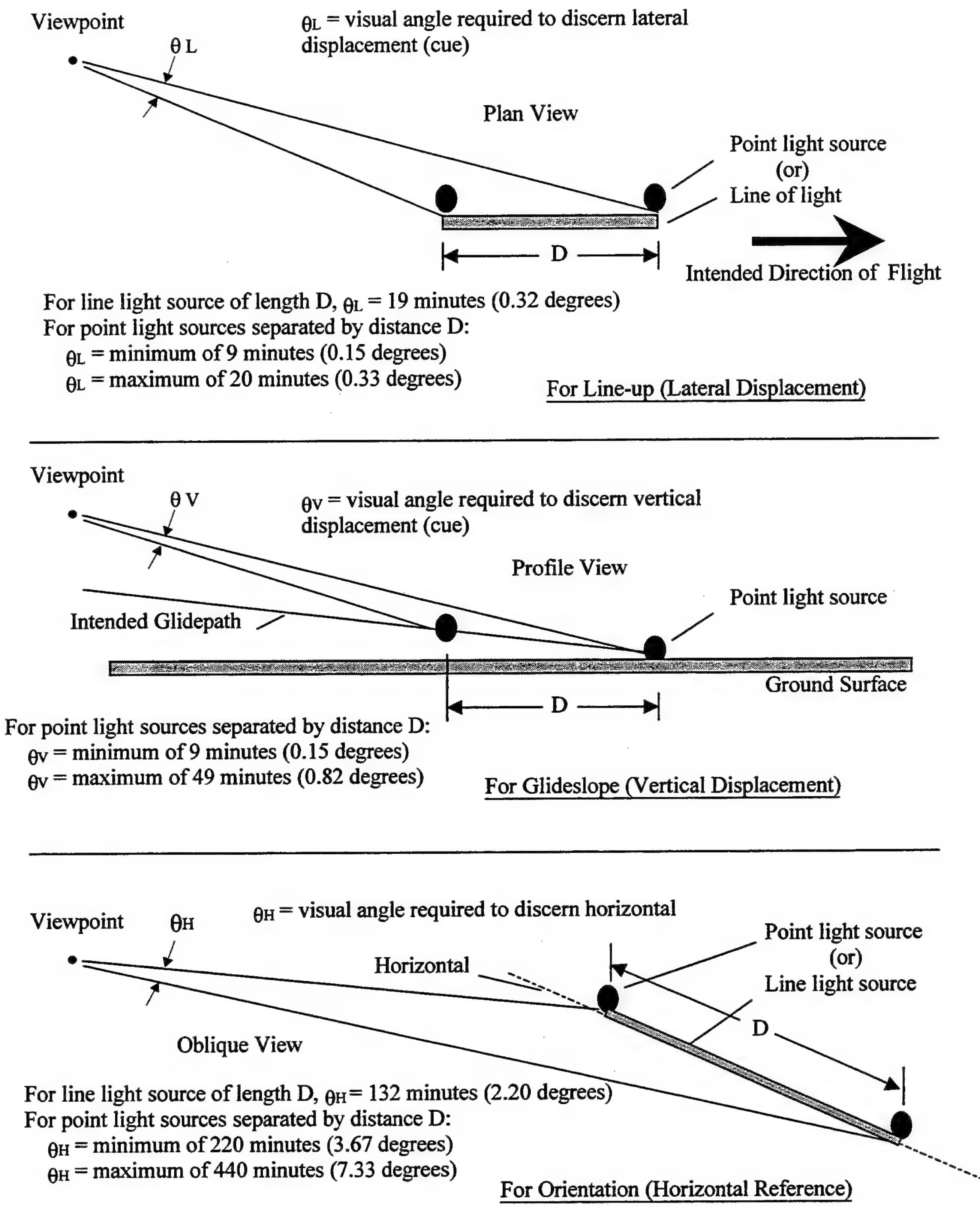

Figure 1 Visual Angle Requirements (Based on Observer Capabilty)

This lighting product is predominantly used for edge lighting, taxiway lighting, and pad layout lighting. However, it could also be used for line-up or glideslope arrangements. The average lamp life span is from 28,000 to 45,000 hours. Changing the frequency can vary intensities. Currently, electroluminescent lighting is being manufactured with frequencies at 60 Hz and 400 Hz. Both types are currently in use at heliports. The 400 Hz lighting is considerably brighter than the 60 Hz lighting.

Advantages:

- Reliable
- Low current requirements
- Thin profile (can be installed as flush lighting)
- Flexible
- Can withstand very hot or very cold temperatures
- Can withstand snow, rain, etc.
- Does not produce "white outs"
- Available in various sizes and shapes (per customer request)
- Light weight
- Long life
- Easy maintenance
- Different colors

Disadvantages:

- Cost
- Low light output
- Hard to spot in high light environments
- No heat generated to melt snow/ice/frost
- Can not be seen at low angles unless it is installed at an angle
- When installed at an angle, the potential obstruction hazard must be addressed

<u>Visible Lasers</u>

Visible laser lights can be used for glideslope information and line-up information. They create a visual line in space that does not represent an obstruction.

Laser technology for use in the helipad environment represents an effective means for providing the pilot with acquisition and line-up information. The problems associated with a laser lie in the application of the technology to pad lighting environments. Current technology lasers require large amounts of power, precision optics, and in most cases a continuous flow of cooling water for operation.

Two particular examples of this are lasers as used by the United States Coast Guard for marking waterways, and lasers used for amusement light shows. Both of these operations require visible

lasers. By definition, visible transit lasers are lasers that show the path of travel of the beam without the need for a diffusion medium.

Both of the above systems required high energy lasers with power requirements in excess of 6 kilowatts for the Coast Guard system manufactured by Laser Ionics Inc., and in excess of 9 kilowatts for the amusement lighting system developed by Coherent Technologies. Both of the systems have cooling water requirements.

Cost is another factor that must be considered. Both systems described had a unit cost of about $75,000. Large production quantities might reduce this cost to about $30,000 per unit. For heliport lighting, such a system does not have a practical cost/benefit relationship. Other less costly systems can be employed to provide the required helipad lighting. As the technology becomes more mature, effective use of lasers may be a possibility. Spangler (reference 5) indicates that new systems may not be far off, noting that "the laser has a promising future as a Coast Guard short-range navigation aid, especially with new technology being developed, such as solid state lasers, which are smaller and cheaper to operate, and they are right around the corner."

Advantages:

- Provides a visual line in space
- High intensity light

Disadvantages:

- Eye safety issues
- Extremely high cost
- Requires a large amount of power
- Some lasers require cooling water
- Requires high maintenance
- Low production item
- Daytime visibility may be restricted by "eye-safe" intensity limit

Due to the high costs, possible requirements for cooling water, and maintenance, lasers are not recommended at this time. As technology develops and production costs decrease, lasers may become a more logical selection as one component of a heliport lighting system.

<u>Light Pipe or Light Bar</u>

This type of lighting aid might provides the pilot with line-up and glideslope information and edge lighting, as well as obstruction marking. The voltage needed to support these systems is about 10 to 30 volts for DC or 120 to 480 volts for AC.

The "lite-pipe" is manufactured by Automatic Power of Houston, Texas. The device is a cylindrical pipe that emits a uniform light along the length of the pipe. The lite-pipe is a sealed fluorescent light source with a ballast at each end. The intensity of the light is uniform along the length of the pipe. The design has a long life and is presently used to mark waterways and bridges. The lite-pipe can provide a wide color range, and also has the ability to restrict the output angle. Shielding can be used to limit the light output from 20 to 360 degrees.

The use of the lite-pipe in the heliport environment offers the ability to transition from the commonly used point source to a line of light. These lines may provide a clearer indication of location, glideslope, and outline than can be provided by the point source. These lite-pipes can be seen as a low-cost replacement for visible lasers. The acquisition cost of the lite-pipe is around $5,000 for a 20-foot section of any color.

Advantages:

- Produces a single line of light
- Provides high intensity lighting up to 400 watts per foot
- Can be sized up to 40 feet
- Eye safe
- Long life
- May be synchronized
- Available in a wide variety of colors
- Several viewing angle options are available
- Can be used day or night
- Easy servicing
- Low maintenance

Disadvantages:

- High cost
- Intensity varies with color selection
- Subject to damage by strong winds
- If made too short, it can appear as a point source from a distance

<u>Strobe Lights</u>

Strobe lights could be used for acquisition lighting and obstruction lighting.

Advantages:

- Wide range power output
- Generally small in size
- Extremely reliable
- Omni-directional

- Sharp low beam cutoff
- Output shaped to avoid ground illumination

Disadvantages:

- Retina "after-image"
- Potential for pilot spatial disorientation

High Intensity Strobe Beacon for Acquisition

This high intensity strobe has the following relative characteristics:

Advantages:

- Reliable
- Requires no high voltage wiring
- Minimum wind loading
- Self-monitoring
- Low power consumption
- Minimal maintenance cost (no moving parts)
- Fairly long life
- Flashes Morse code "H"
- Simple to install
- Small in size

Disadvantages:

- High cost
- Neighbors may object

Flush Surface Lights

Flush surface lights are installed in the surface of the helipad. They assist the pilot in the final phases of flight such as hover and touchdown.

Advantages:

- Flush with surface, no obstruction hazard
- Provides an omni-directional spread of light
- Easy to install
- Weatherproof
- Low cost
- Small in size
- Can be electroluminescent or incandescent lights

Disadvantages:

- Watertight enclosure required
- At a distance, they cannot be seen as well as elevated lights

Flood Lights - Surface Mounting

Surface floodlights might be used to light the helipad at night or during IMC. They require 120 volts AC power.

Advantages:

- Provides better heliport lighting than perimeter lights
- Reduces the glare on the heliport caused from lights
- Requires low power output
- Intensity is easily varied
- Low cost

Disadvantages:

- Obstruction hazard (involved in at least one serious heliport accident)
- Glare impacting pilot night vision
- Potential for breakage

Perimeter Lights

Perimeter lights were designed to outline the heliport. They use 120 volts AC.

Advantages:

- Small in size
- Low profile
- Surface mounted
- Weatherproof
- Low cost

Disadvantages:

- Available in a limited number of colors

Pulse Light Approach Slope Indicator (PLASI)

The PLASI is used for the sole purpose of glideslope displays. It uses a three-color unit to help the pilot determine the proper glideslope. This unit requires 120 volts AC and operates on a frequency on 50-60 Hz. This is a superset of the visual approach slope indicator (VASI) and Chase heliport approach path indicator (CHAPI) type systems.

Advantages:

- Automatic bulb replacement
- Can also be made portable
- Has multiple glideslope angle capabilities
- Low maintenance cost
- May be controlled on the ground or in the aircraft
- Reliable
- Reasonable cost
- Easy to set new glideslope
- Requires only a single position for installation of all ground components.

Disadvantages:

- Provides only three reference states: high, low, or on glideslope
- Low light output compared to other systems
- High maintenance cost due to large number of moving parts

Cold Cathode Lights

Cold cathode lights show promise for use as an acquisition aid and as a perimeter lighting aid. Cold cathode lights do not leave a retina after-image. Preliminary testing indicates that there was no retina after-image even after looking directly at the lights. For this reason, some advocates have suggested that the retina records the light, but is not "burned" by the light, thus leaving no after image.

Advantages:

- Low initial cost
- Can operate using battery power
- Portable installation
- Does not degrade the pilot's night vision

Disadvantages:

- Low intensity

3.5 POTENTIAL APPLICATIONS

Lighting devices using point source technologies are useful in many situations and have been applied in most cases to date. It should be noted, however, that such technologies might have limitations when producing continuous light lines. As the aircraft nears the light sources, the line "breaks apart" and the individual point light sources become visible. However, as other research has shown (section 5.4), this property may be useful in producing closure rate cues.

A source that contrasts with the background is best suited for acquisition. In the United States the standard heliport acquisition beacon is a rotating 3-color beacon (white-green-yellow). The international standard is a pulsing high intensity strobe whose strobe rate is the Morse code "H" for heliport. Several years ago, the FAA performed a test (reference 7) to determine pilot preference for the two beacons. The results showed that both beacons had strengths and weaknesses and there was no strong pilot preference. However, during the evaluation described in reference 8, one pilot found that during restricted visibility conditions a radio-controlled, high intensity strobe allowed him to quickly acquire the heliport environment.

Line-up is presently achieved by following light source "lines" composed of a series of incandescent sources mounted on or near the ground in a horizontal line along the approach path. Such light lines will continue to be used, but might be improved by substituting a light source that provides or looks like a continuous line of light. Again, the continuous lines would be more easily distinguished from unrelated, near-by point sources.

To be effective near the heliport during low-ceiling approaches, ground-mounted light arrays must be located beyond the heliport (opposite the direction of approach). Although cockpit geometry (field of view) and related pitch attitude effects are beyond the scope of this report, it should be noted that these factors have a major impact on the array location.

To cope with cockpit visibility problems, it would be helpful to install line-up lights at some reasonable height above the ground. Unfortunately, the erection of structures to support such lighting creates obstructions. This is a particularly critical disadvantage in the case of precision approach systems where the approach surfaces are broader and less steep than VFR approach surfaces. For this reason, the provision of suitable line-up cues is one of the challenges in the design of the lighting array.

Visible laser beams (projected vertically) would provide easily observed line-up cues at any pitch angel, and would not represent an obstruction. If the problems of eye safety and cost requirements for cooling water could be overcome, the laser might represent a very effective solution.

Glideslope cues are often provided by color-coded signals. Other systems such as the Mirror Optical Landing System (MOLS) (figure 2) and Fresnel Lens Optical Landing Systems (FLOLS) military types use visual disparity between light lines and light points as a cue. Most existing glideslope lighting systems provide little or no orientation cues (to the horizon).

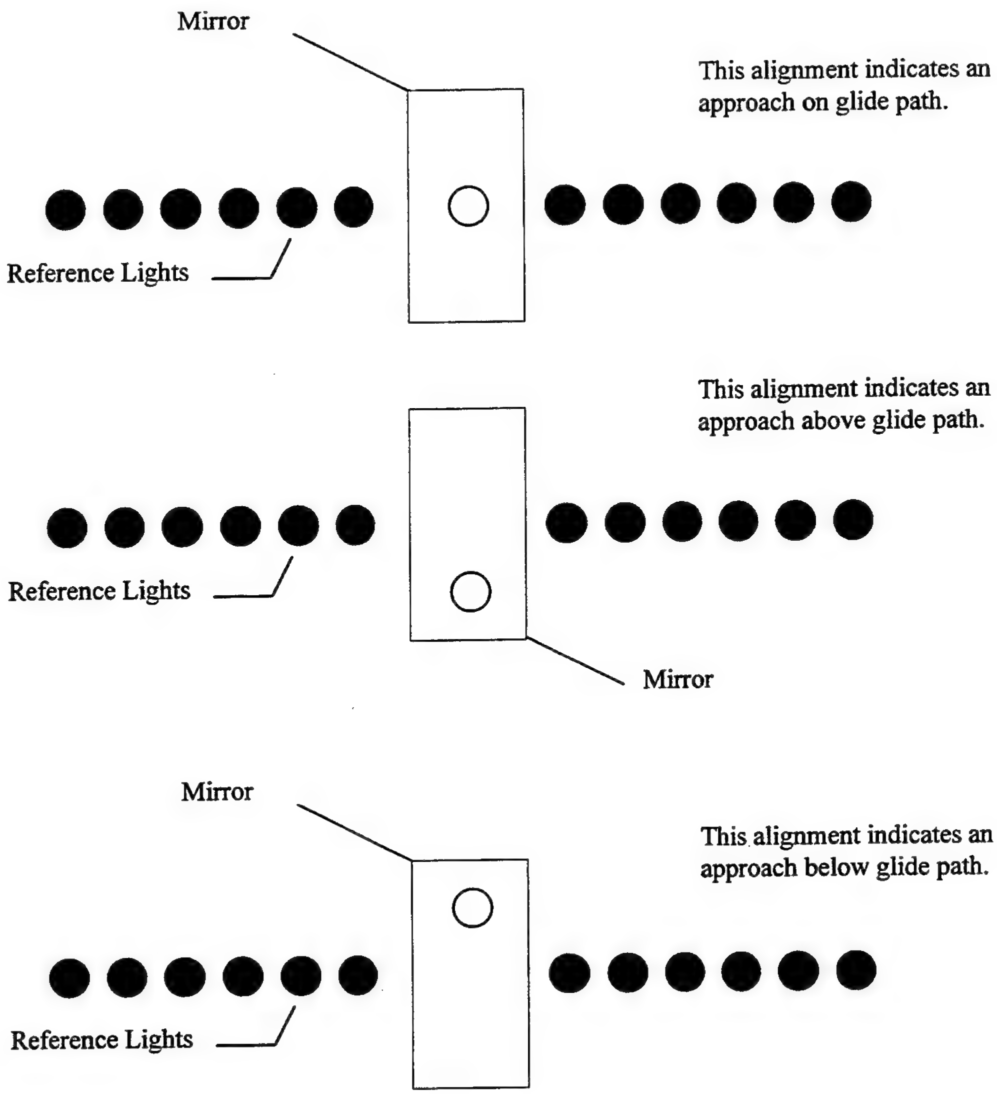

Figure 2 Mirror Optical Landing System (MOLS)

Horizontal light lines, composed of fore and aft arrangement of light pipes, can be applied to both glideslope and orientation cues. Such applications may prove to be less complex and less costly than the more common point source glideslope systems presently available. Placement on the far side of the heliport and the addition of a vertical adjustment feature will complement the light line glideslope system (see figure 3). In addition, their larger size relative to point source glideslope systems is an advantage in identifying and acquiring the lighting system. However, size is also a disadvantage because the light line glideslope system requires more real estate (approximately 40 feet by 90 feet) than point source glideslope systems.

In the case of closure on the heliport, establishing a “pattern shape” is important in order to capitalize on the optical expansion rate cue. Point light sources are effective for this purpose and contribute in combination with the hover and touchdown system described in figure 4. Incandescent point sources represent a cost-effective system for defining the pattern shape.

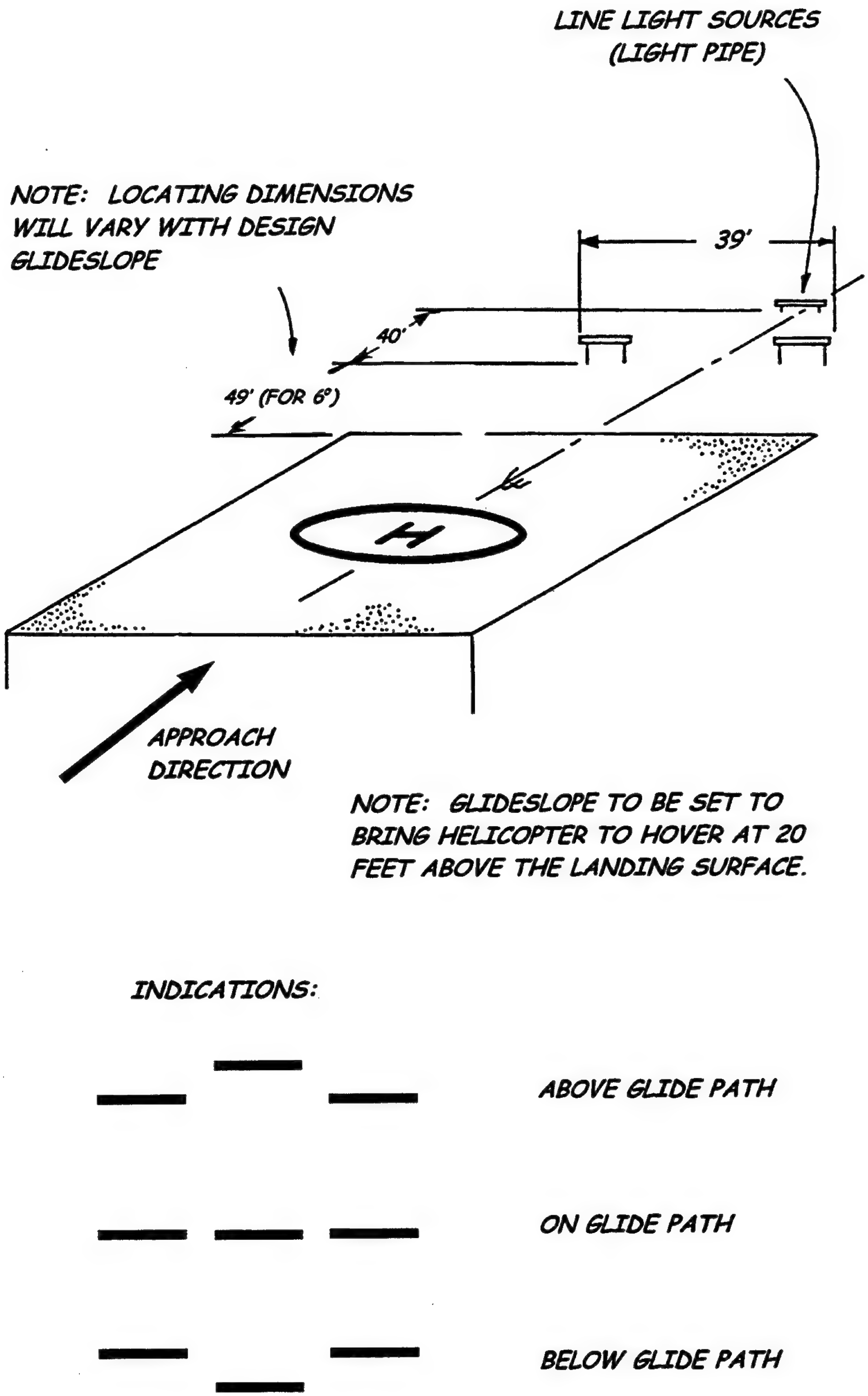

Figure 3 Helicopter Approach Glideslope

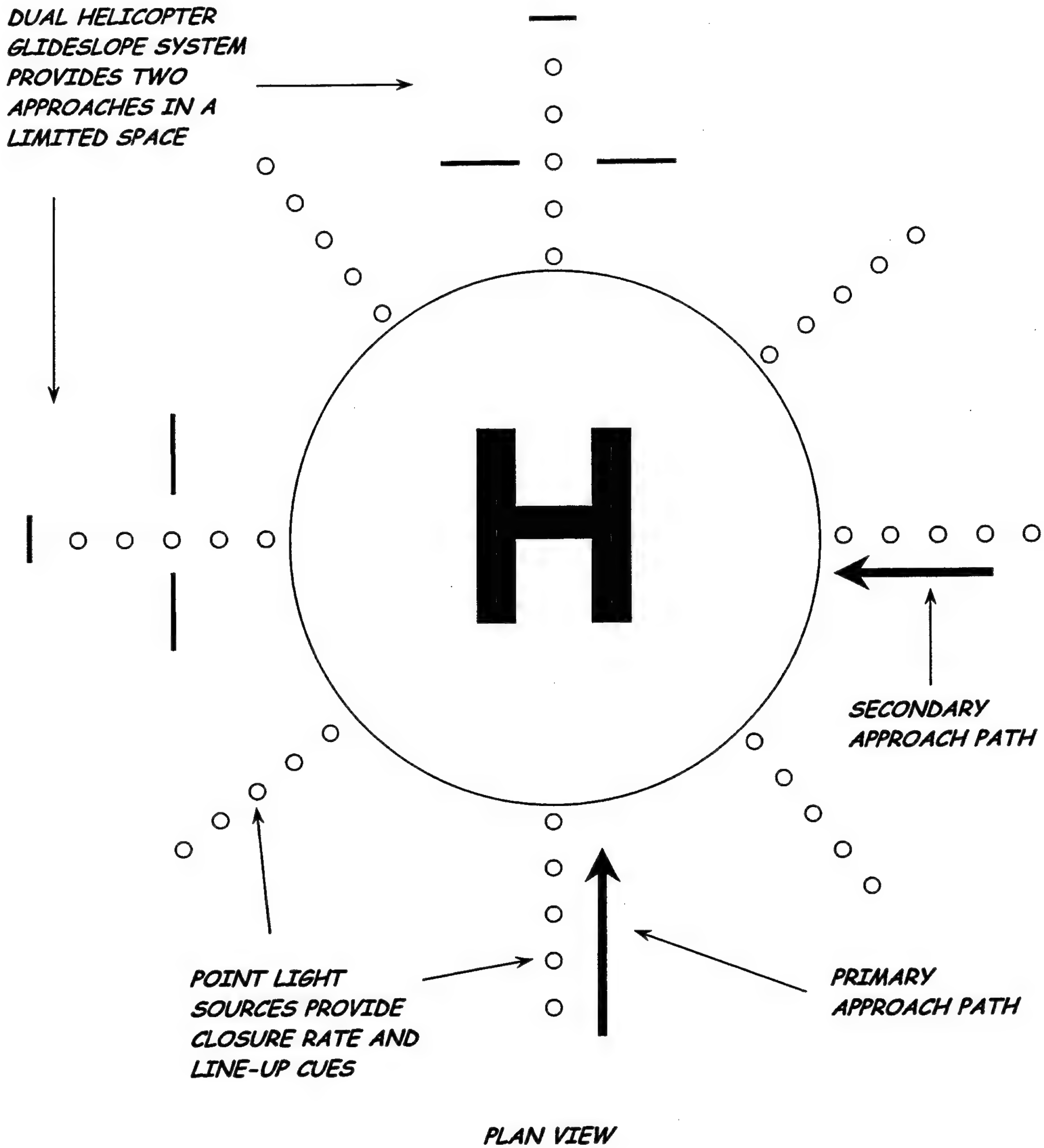

Figure 4 Pattern of Lights Provides Line-Up and Closure Rate Cues

In summary, lighting technologies cannot be separated from the geometry of the technology application. Isolated treatment of these two elements will generally not produce a solution that capitalizes on the best features of the technology itself. The conclusions discussed in Section 5 of this report (as a basis for testing) therefore include considerations of both arrangement and spacing dimensions of light sources.

3.6 MANUFACTURER SUPPORT

The survey of lighting manufacturers has shown a desire to help develop more sophisticated lighting technologies for use by helicopters. Fourteen helicopter lighting manufacturers were contacted to determine possible support for investigating new methods of lighting. All fourteen responded positively. Two have supplied equipment for tests, one has visited our location and provided a holder for the MOLS demonstration, and all those questioned would support the project by supplying items at cost or at no charge during the tests.

4.0 TESTING AND SIMULATION

As a part of the project, UTSI conducted some limited field testing of glideslope lighting systems. UTSI also developed a method to simulate and test a complete helipad lighting array in small scale in a darkroom. Both of these projects proved very successful and were done on extremely low budgets.

4.1 MOLS FIELD TEST

The first test project was to compare a Mirror Optical Landing System (MOLS) (used on Navy Aircraft Carriers for approach slope guidance) with current helicopter approach glideslope systems such as PLASI.

The purpose of MOLS is to provide to the pilot an indication of angular displacement from the approach glideslope (see figure 2). The system provides the pilot a set of reference arms to the left and right of a center light source. This centerlight source appears to moves up and down as a function of pilot viewing angle. If the pilot is on the glideslope, the yellow ball in the center will appear between the two reference arms. If the pilot is above the glideslope, the yellow ball will be above the reference arms. If the pilot is below the glideslope, the yellow ball will be below the reference arms. The mirror serves to focus the remote lights that form the yellow ball. The center "ball" provides error magnitude and error rate information as to the helicopter glideslope closure, while the PLASI provides only error magnitude information (i.e., red, white, or green). The error rate information allows the pilot to reduce the correction as the aircraft nears the "on glideslope" position. The remote reference lights are located a minimum distance of 100 feet away from the light stand. The glide path angle is a function of both the stand tilt angle and the position of the remote lights. The display aspects of the system are illustrated in figure 2.

The MOLS test was accomplished by locating the mobile MOLS at the Erlanger Hospital helipad in Chattanooga TN and aligning it with the non-precision GPS approach to the helipad. Four Erlanger Life Force pilots in then flew this system over a period of six months in a Bell 412 helicopter. Pilot surveys were conducted for 12 approaches (7 day, 5 night, with 4 of the total flown with a visibility of 5 NM or less). Surveys of pilot opinions showed the MOLS to be superior to the installed PLASI system.

Due to the large physical size of the MOLS, pilots noted that it provided rate-of-closure information on the glideslope that was not available on the PLASI. They also indicated that it provided limited line-up information.

Visual acquisition of the MOLS was exceptional at long range. It is interesting to note, however, that some difficulty was evident in picking up the yellow source light, particularly at night. No such difference was apparent with the green datum lights. This indicates that the "dark adapted" pilot eye is more sensitive to the wavelengths in the green part of the vision spectrum.

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Problems encountered with the use of the MOLS were maintenance related and included light failures during approach, mirror fogging in certain weather conditions, or attempts to use the MOLS for a glideslope angle for which it was not aligned.

Discussions with individual pilots also revealed a desire to have glideslope information located beyond the helipad with the guidance set to avoid obstacles to guide the pilot to a point above the heliport at 20 to 50 feet. The pilots would then fly beneath the glideslope to the helipad when a visual inspection of the landing area assured them that no obstacles were in their path. Such guidance would provide adequate clearance for the tailrotor during any final flare in coming to a hover over the pad.

4.2 LIGHTING ARRAY SIMULATION (SCALE MODELS)

The second test project was to develop small helipad lighting arrays and test them in a dark room. The method used cardboard boxes to simulates the heliports with the lighting provided by miniature Christmas tree lights. The heliport arrays were laid out to a scale of ¼ inch equals one foot, which allowed viewing from scale distances of 2,600 feet in the room available. Three basic arrays were examined, with several variations in each case. Six helicopter pilots of varying levels of flight experience evaluated the arrays from 3, 6, and 9-degree approach angles. Five of the six pilots preferred the array with lights arranged radially around the pad as is shown in figure 4 on the basis of approach and landing operations. The other pilot preferred the offset array as shown in figure 5.

Although the test was limited in scope, it did prove the efficiency of analog modeling in developing a concept prior to testing in full-scale visual simulators or in actual flight tests.

An array is very inexpensive and can be assembled in less than four hours. Such a method allows for rapid, low-cost prototyping of a large number of arrays to determine the best layouts for further development. Such a technique is a useful, cost-effective first step in future lighting array development.

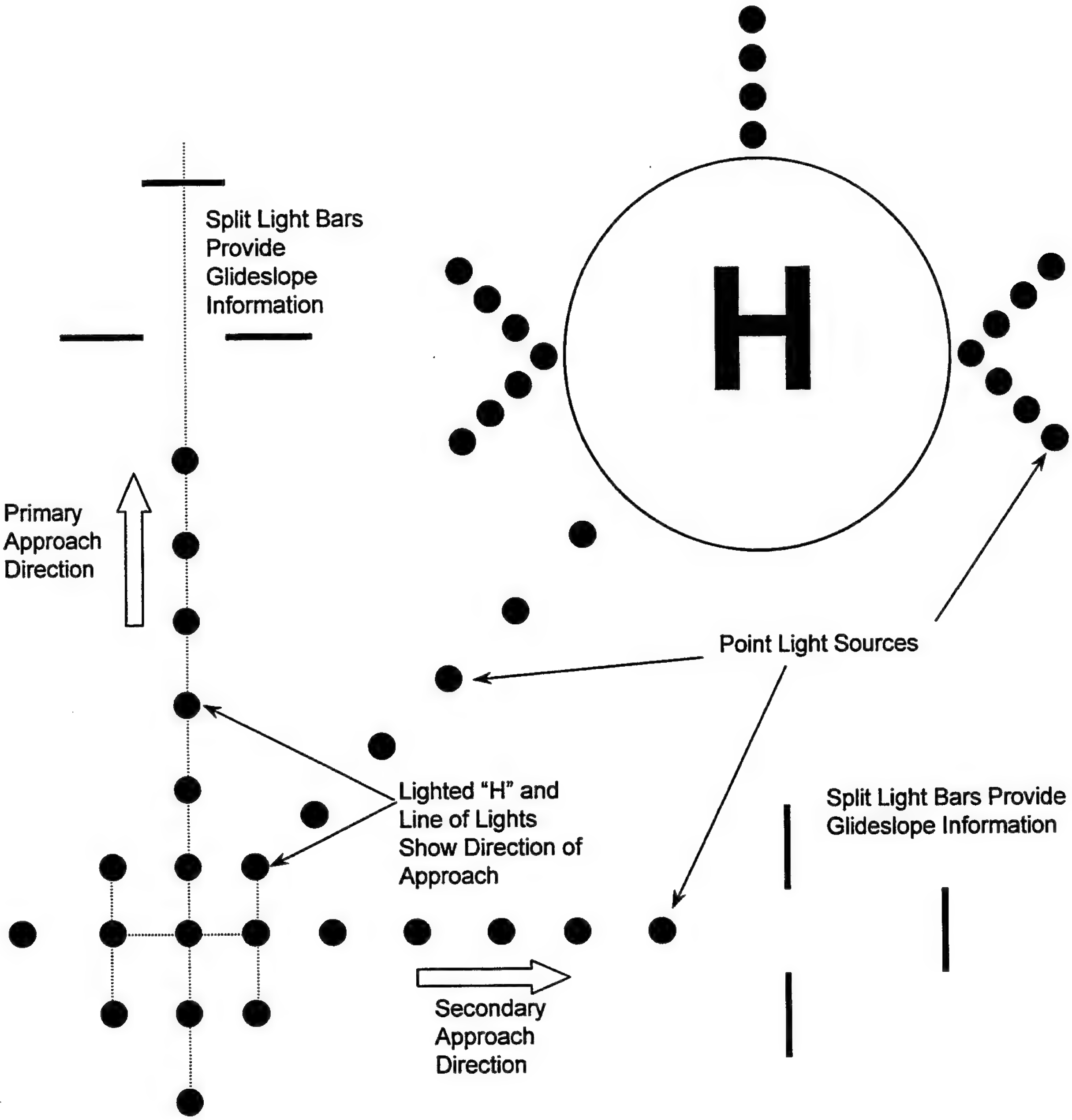

Figure 5 Lighting Configuration to Provide Two Offset Approaches to a Heliport

5.0 CONCLUSIONS (CRITERIA FOR TEST)

The following conclusions are based on the lighting technologies discussed above, and are offered as a basis for designing a test program:

5.1 ACQUISITION

Consider a light source that contrasts with background (ambient) light sources. In an urban setting, background sources are largely steady points of light, thus select either a line or pulsing source.

Note that the visual acquisition will involve "searching" (perhaps from an off-course position), and this will use the peripheral edges of the retina of the eye. Since this region is sensitive to movement, but not color, and is efficient in a "dark adapted" state, a pulsing source (white) is best for acquisition.

5.2 APPROACH (LINE-UP)

Consider sources that provide sufficient visual angle disparity to cue both off-course condition and required correction. Ensure that line-up information is available along entire approach path (in all approach attitudes). Thus install a series point light sources of sufficient length (in the pad and extended on the "far side" of the pad) and consider whether it would be appropriate to supplement with a vertical light line on the far side of the pad.

A pair of vertical light lines (separated sufficiently to provide visual angle disparity) can function effectively as a line-up cue, provided that the forward light line can be differentiated from the rear light line. In both cases, the potential of an obstruction hazard must be carefully considered during the evaluation process.

5.3 APPROACH (GLIDESLOPE)

Consider sources that provide sufficient visual angle disparity to cue both an off-glideslope condition and the required correction. This may be accomplished with "light ball" systems such as the FLOLS or the earlier MOLS. A number of point source approach path lighting systems, described herein, provide a horizon reference. Thus a line source system which will provide both glideslope and horizontal orientation is suggested. A set of three horizontal light lines may be considered for this purpose. In this design, the front-to-rear separation would need to be sufficient to produce a recognizable visual angular disparity at the required range. The total length of the light line would need to be sufficient to provide a visual angle that can be interpreted as a horizon. During evaluation, the potential of an obstruction hazard must be carefully considered.

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5.4 CLOSURE (RATE)

In many cases, it will not be possible to install a long array of approach lights in front of the pad. In addition, many of the point light sources in such a system turn out to be underneath the helicopter cockpit cutoff angle under low weather minimums. Thus, an alternative approach to closure rate determination is required. In the absence of specifically-spaced approach lights, as in the Helicopter Approach Lighting System (HALS), the "optical flow rate" (angular flow rate of surface features passing through the field of view) and "optical edge rate" (frequency of passage of uniformly spaced elements through the field of view) cues are not available. Thus, the optical expansion rate (growth in optical size of an image as the object is approached) would be the only effective cue available for this purpose. In this situation, the rate of growth of the size of the pad in the field of vision as the approach is flown provides the cue to closure rate. Due to the requirement to decelerate the aircraft to a hover over the heliport, this cue is more important in operations to a heliport rather than an airport. The expansion rate cue becomes important at an approximate distance of 300 to 400 feet from the heliport.

Perhaps a better way to accommodate the visual requirements in this case is to define the pad surface to a degree sufficient to enhance the perception of expansion. Radial point light sources may indeed represent a solution, and contribute visual support to the hover and touchdown operations at the same time.

Since the eye focuses on the pad, the foveal region of the retina is used. This region provides visual acuity (sensitivity to detail). For this reason, the addition of texture to the pad surface could significantly enhance the optical expansion rate/closure rate determination. Surface texture can be created through marking, but it should be noted that present heliport marking concepts (reference 6) do not necessarily attempt to capitalize on this possibility. Although marking was not specified as an item for investigation under this project, it is suggested that marking with regard to creating texture be investigated in the next phase of the project, as an item which could enhance safety and reduce pilot workload in the visual segment of an instrument approach.

5.5 LANDING (FLARE, HOVER AND TOUCHDOWN):

Point source perimeter lights and supplementary point source "edge bars" and "wing bars," as described in the current Heliport Design Advisory Circular (reference 6), have traditionally been used to provide guidance in final landing maneuvers. Floodlights that "wash" the heliport surface represent reasonable touchdown visual guidance. Physical shielding may reduce negative impacts of floodlighting on pilot night vision.

Cues are needed to aid the pilot in centering the aircraft over the pad. The lines of radial lights proposed as closure rate guidance all point to the center of the heliport, and may be more effective than the present standard perimeter system in supporting the hover and touchdown operation.

Table 3 summarizes the proposed testing of candidate lighting technologies. Note that in some of the cases more than one technology is suggested for consideration.

Table 3 Candidate Lighting Technology Applications

	Lighting Technology Type				
Operational Phase	Point Source	Interrupted Source	Electroluminescent Panel	Light Pipe	Laser (Beam)
Acquisition		Strobe beacon			
Line up	Horizontal, Ground - Mounted		Horizontal, Ground - Mounted		Dual Vertical Light Lines
Glideslope			Fore/Aft Set	Fore/Aft Set	
Closure	Radial, Ground - Mounted			Radial, Ground - Mounted	
Hover/ Touchdown	Floodlights, Ground - Mounted		Panels in the Form of the Standard Heliport Marking Symbol (H)		

6.0 RECOMMENDATIONS FOR TEST

Based on the lighting technology information previously discussed, and on the conclusions (criteria for test) drawn from this investigation, a series of tests are recommended. It is assumed that the beginning point (breakout) for the test approaches will be variable based on the initial approach speed, deceleration rate, weather ceiling/visibility and glideslope as dictated by other program test requirements. Figure 6 illustrates the height-range relationships for the proposed glideslopes. It is also assumed that test approaches will be flown both day and night under varying meteorological conditions. In each of the recommended test cases the variables to be investigated are listed below. Comments regarding special conditions are also included.

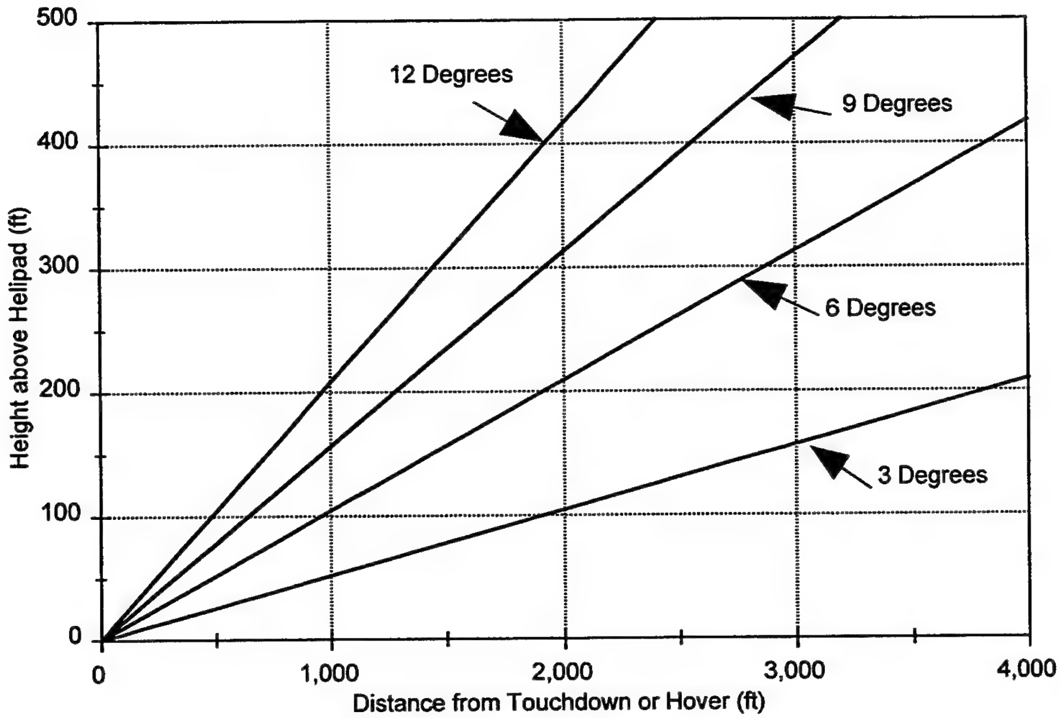

Figure 6 Distance – Altitude Relationships for Various Glideslope Angles

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- Acquisition

  Test a continuous line of light located on or near the heliport.

  In a low visibility environment, test a radio-controlled pulsating light beacon (strobe) located on or near the heliport.

  Evaluation:
  Determine distance for visual acquisition with breakout at variable range and altitude.

  Location:
  Test in both urban (city center) and remote sites under restricted visibility conditions.

- Line-up (See figure 7)

  Test a horizontal light line of point sources 60 feet in length. This is the length required to subtend a visual angle of 19 minutes viewed from a slant range of 1,000 feet at 100 feet AGL.

  Vary the position of the horizontal line starting at the center of the pad and also at the back edge of the pad. Vary the number of point sources and spacing. Enhance the system with a vertical light beam set 80 feet beyond the pad centerline.

  As an alternative, erect a vertical line of point sources set behind the final approach reference area to a height which does not penetrate the approach surface. As an alternative, substitute a vertical line light pipe for the point light sources. (Since this presents a potential obstruction hazard, it should not be used unless there is already an existing obstruction of comparable height.)

  Evaluation:
  Determine the effectiveness of variables by pilot rating.

- Glideslope (See figure 3)

  Test a set of three horizontal light lines (light pipes) spaced 39 feet apart (longitudinally) and located behind the pad. This is the length required to subtend a visual angle of 15 minutes to detect visual disparity at a slant range of 1,00 feet and a 10 percent variation in altitude from glideslope. Set forward light pipes at a location and height, that will bring the helicopter to a hover 20 feet above the heliport surface. The horizontal light pipes should be kept as low as possible to avoid becoming obstruction hazards.

Test light bars of 13 feet in length (each) for a total combined spread of 39 feet. (Also test for a total combined spread of 43 feet, 47 feet, and 51 feet.) This is the width required to subtend a visual angle 132 minutes from a slant range of 1,000 feet. Vary the glideslope setting by vertical adjustment of the rear (center) light bar.

Evaluation:

Determine the effectiveness of the light bar glideslope system by pilot rating.

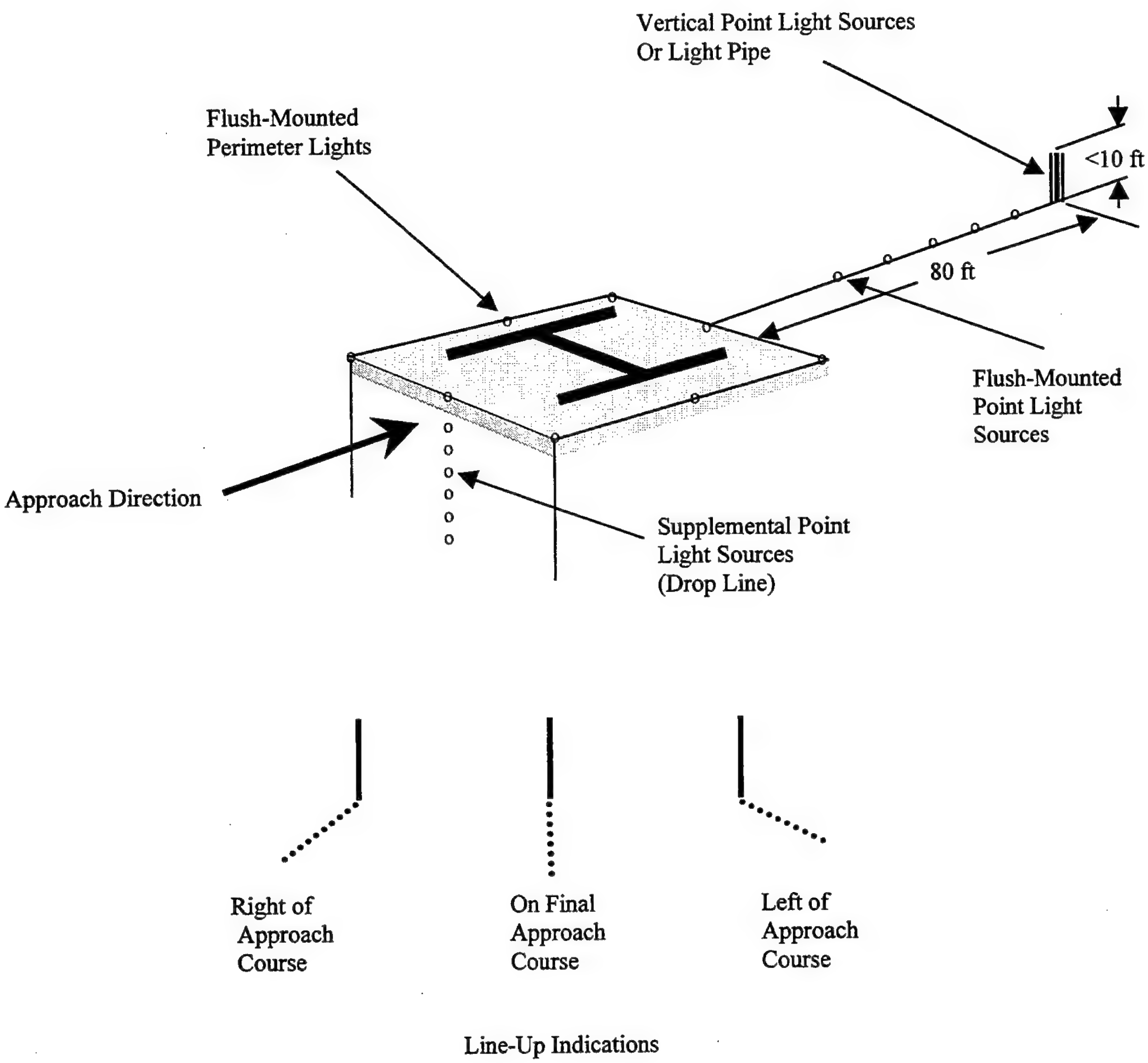

Figure 7 Helicopter Approach Line-Up System

- Closure Rate (See figure 8)

  Test the radial light array with fixtures set around the heliport area [8 line-of-light rays (created by point light sources in individual fixtures) spaced 45 degrees apart]. Vary the length of the ray, and the number and spacing of fixtures. Test at heliports designed for "design helicopters" of different sizes.

  Evaluation:

  Determine the effectiveness of the landing light system by pilot rating. Evaluate the extent to which the radial array makes the helipad appear larger. Evaluate the effectiveness of the array for providing an optical expansion rate cue. Determine the minimum length of the rays, the minimum number of fixtures, and the maximum spacing between fixtures.

- Landing (See figure 8)

  Test floodlight system which will "wash" the heliport surface area. Note that the outer boundary of this area should be marked (for size delineation).
  Use multiple fixture mountings as required.
  Vary time at which floodlights are turned on and off during the approach.

  Evaluation:

  Determine the best floodlight operating sequence by pilot rating.

For the most part, the above recommendations involve the use of fixtures and equipment that are presently available. Some fabrication of mounting devices may be necessary in some cases. For purposes of test, the light sources should be easily movable in order to allow experimentation with locating, spacing, and fixture numbers.

Two specific final recommendations should be considered prior to proceeding to the test phase:

1. The possibility of enhancing the proposed lighting systems with the application of color should be explored.

2. In order to enhance the closure rate cues, the possibility for emphasizing pad texture by special marking (that is compatible with the installed lighting system) should be explored.

Test activities should be carried out to ensure the best possible results at the least possible cost. Innovative procedures should be introduced whenever possible in order to meet the cost objectives. Modeling in some instances may represent the least cost alternative, but in certain cases, it will not be possible to model the concept in a realistic way. A well planned and

implemented flight test, done in concert and combination with other required full-scale field flight tests may well represent the "least cost" approach to the lighting system test.

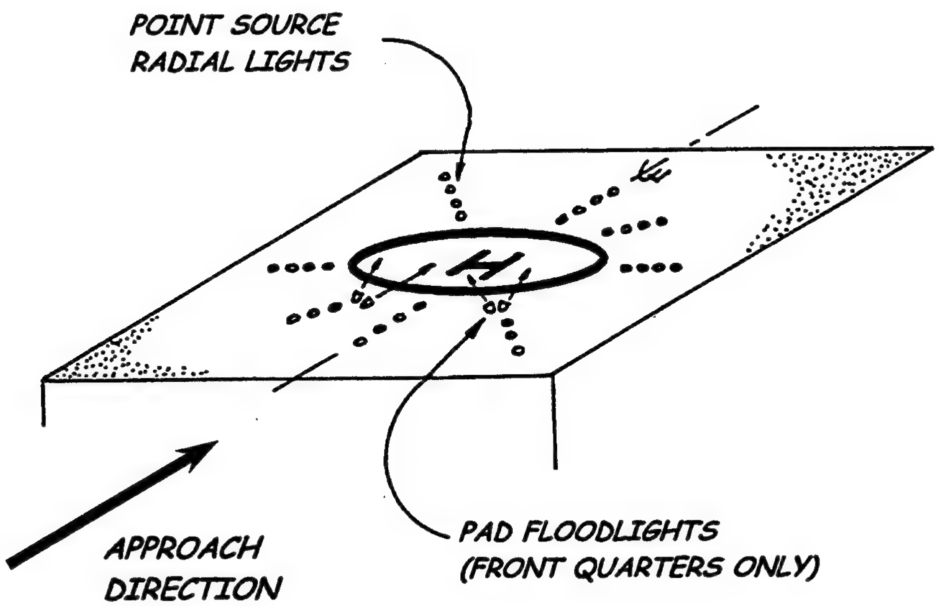

Figure 8 Heliport Surface Lighting System

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APPENDIX B

ACRONYMS

AC	Alternating Current
AGL	Above Ground Level
CHAPI	Chase Helicopter Approach Path Indicator
DC	Direct Current
FAA	Federal Aviation Administration
FLOLS	Fresnel Lens Optical Landing System
GPS	Global Positioning System
H	Symbol for a Civil Heliport
HALS	Heliport Approach Lighting System
HILS	Heliport Instrument Lighting System
Hz	Hertz
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
MOLS	Mirror Optical Landing System
NAS	National Airspace System
nm	Nautical Mile
NTIS	National Technical Information Service
PLASI	Pulse Light Approach Slope Indicator
SAIC	Science Applications International Corporation
TERPS	Terminal Instrument Procedures
TN	Tennessee
UTSI	University of Tennessee Space Institute
VFR	Visual Flight Rules
VASI	Visual Approach Slope Indicator